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**for**

**Contract N00014-86-K-0427**

**R&T Code s400016srf**

**Formation of Defect-Free Metal/Semiconductor Contacts**

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**15 December 1992**

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PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT**

R&T Number: s400016srf

Contract/Grant Number: N00014-86-K-0427

Contract/Grant Title: Formation of Defect-Free Metal/Semiconductor Contacts

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- a. Number of papers submitted to refereed journals, but not published: 0
- b. \* Number of papers published in refereed journals (list attached): 48
- c. Number of books or chapters submitted, but not yet published: 2
- d. \* Number of books or chapters published (list attached): 1
- e. \* Number of printed technical reports & non-refereed papers (list attached): 1
- f. Number of patents filed: 0
- g. \* Number of patents granted (list attached): 0
- h. Number of invited presentations at workshops or professional society meetings: 23
- i. Number of presentations at workshops or professional society meetings: 37
- j. \* Honors/Awards/Prizes for contract/grant employees (list attached): 3  
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Post-Doctoral Associates: 8  
including the number of,  
Female Graduate Students: 0  
Female Post-Doctoral Associates: 0  
the number of  
Minority\* Graduate Students: 1  
Minority\* Post-Doctoral Associates: 0  
and, the number of  
Asian Graduate Students: 1  
Asian Post-Doctoral Associates: 4
- l. \* Other funding (list agency, grant title, amount received this year, total amount, period of performance and relationship of that research to your ONR grant)

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**Part I****a. Papers Submitted to Refereed Journals (and not yet published)**

None

**b. Papers Published in Refereed Journals during Funding Period**

1. S.A. Chambers, D.M. Hill, F. Xu, and J.H. Weaver, "Silicide Formation at the Ti/Si(111) Interface: Diffusion Parameters and Behavior at Elevated Temperatures," *Phys. Rev. B* **35**, 634-640 (1987)
2. M. del Giudice, J.J. Joyce, M.W. Ruckman, and J.H. Weaver, "Silicide Formation at the Ti/Si(111) Interface: Room-Temperature Reaction and Schottky-Barrier Formation," *Phys. Rev. B* **35**, 6213-6221 (1987)
3. F. Xu, Yoram Shapira, D.M. Hill, and J.H. Weaver, "Atom Profiles of Interfaces with Polar-Angle-Dependent Photoemission: Au/GaAs(100)," *Phys. Rev. B* **35**, 7417-7422 (1987)
4. F. Xu, Zhangda Lin, D.M. Hill, and J.H. Weaver, "Temperature-Dependent Reaction and Buried-Interface Movement for Ti/GaAs(100) and Cr/GaAs(100)," *Phys. Rev. B - Rapid Commun.* **36**, 9353-9356 (1987)
5. S.A. Chambers, M. del Giudice, D.M. Hill, F. Xu, J.J. Joyce, M.W. Ruckman, and J.H. Weaver, "Silicide Formation at the Ti/Si(111) Interface," *J. Vac. Sci. Technol.* **5**, 1508-1509 (1987)
6. M. del Giudice, J.J. Joyce, F. Boscherini, C. Capasso, and J.H. Weaver, "High-Resolution Core Level Studies of Interdiffusion and Reaction at Metal-Semiconductor Interfaces," *Materials Research Society Symposia Proceedings* **77**, 277-282 (1987).
7. Yoram Shapira, F. Xu, D.M. Hill, and J.H. Weaver, "Use of Angle-Dependent Photoemission for Atom Profiling: Au on Compound Semiconductors," *Appl. Phys. Lett.* **51**, 118-120 (1987).
8. F. Xu, Zhangda Lin, D.M. Hill, and J.H. Weaver, "Temperature-Dependent Interface Evolution for Ti/GaAs(100) and Cr/GaAs(100)," *Phys. Rev. B* **36**, 6624-6630 (1987).
9. Zhangda Lin, F. Xu, and J.H. Weaver, "Surface Segregation at Metal/III-V Semiconductor Interfaces," *Phys. Rev. B* **36**, 5777-5783 (1987).
10. R.A. Butera, M. del Giudice, and J.H. Weaver, "Temperature-Dependent Interface Evolution. Quantitative Modeling of Core Level Photoemission Results for V/Ge(111)," *Phys. Rev. B* **36**, 4754-4760 (1987).
11. F. Xu, C.M. Aldao, I.M. Vitomirov, Zhangda Lin, and J.H. Weaver, "Direct Evidence of the Onset of In Surface Segregation for Co/InP(110)," *Phys. Rev. B Rapid Commun.* **36**, 3495-3498 (1987).
12. F. Xu, J.J. Joyce, M.W. Ruckman, H.-W. Chen, F. Boscherini, D.M. Hill, S.A. Chambers, and J.H. Weaver, "Atom Profiling at Epitaxial Co/GaAs Interfaces," in *Surface Physics, Proceedings of the Asia Pacific Symposium on Surface Physics* (World Scientific, Hong Kong, 1987) pp. 122-130.
13. C.M. Aldao, I.M. Vitomirov, F. Xu, and J.H. Weaver, "3d Transition Metals on InP(110): A Comparative Study of Reactive Interface Evolution," *Phys. Rev. B* **37**, 6019-6026 (1988).

14. F. Xu, D.M. Hill, Zhangda Lin, Steven G. Anderson, Yoram Shapira, and J.H. Weaver, "Temperature-Dependent Reaction and Atomic Redistribution for Ti/GaAs(100) Interfaces," *Phys. Rev. B* **37**, 10295-10300 (1988).
15. D.M. Hill, F. Xu, Zhangda Lin, and J.H. Weaver, "Atomic Distributions Across Metal/III-V Compound Semiconductor Interfaces," *Phys. Rev. B* **38**, 1893-1900 (1988).
16. I.M. Vitomirov, F. Xu, C.M. Aldao, and J.H. Weaver, "Direct Evidence of the Onset of In Surface Segregation for Co/InP(110)," *J. Vac. Sci. Technol.* **6**, 1563-1564 (1988).
17. I.M. Vitomirov, C.M. Aldao, Zhangda Lin, Y. Gao, B.M. Trafas, and J.H. Weaver, "Pd Overlayer Growth on InP(110), GaAs(110), and InSb(110): Comparisons of Anion Surface Segregation," *Phys. Rev. B* **38**, 10776-10786 (1988).
18. C.M. Aldao, I.M. Vitomirov, G.D. Waddill, and J.H. Weaver, "Interface Growth with Atoms and Preformed Clusters: Morphology and Schottky Barrier Variations for Au/InP(110)," *Appl. Phys. Lett.* **53**, 2647-2650 (1988).
19. G.D. Waddill, I.M. Vitomirov, C.M. Aldao, and J.H. Weaver, "Cluster Deposition on GaAs(110): Formation of Abrupt, Defect-Free Interfaces," *Phys. Rev. Lett.* **62**, 1568-1572 (1989).
20. C.M. Aldao, G.D. Waddill, I.M. Vitomirov, and J.H. Weaver, "Interface Formation by Atom and Cluster Deposition: Novel Electronic and Structural Properties," *J. Vac. Sci. Technol. A* **7**, 817-882 (1989).
21. G.D. Waddill, C.M. Aldao, I.M. Vitomirov, Y. Gao, and J.H. Weaver, "Temperature Dependent Interface Morphology and Schottky Barrier Evolution for Au/InP(110)," *J. Vac. Sci. Technol. A* **7**, 865-869 (1989).
22. C.M. Aldao, S.G. Anderson, C. Capasso, I.M. Vitomirov, G.D. Waddill, and J.H. Weaver, "Dopant Concentration Dependences and Symmetric Fermi Level Movement for Metal/n- and p-GaAs(110) Interfaces Formed at 60 K," *Phys. Rev. B Rapid Commun.* **39**, 12977-12980 (1989).
23. C.M. Aldao, G.D. Waddill, S.G. Anderson, and J.H. Weaver, "Temperature Effects for Ti/GaAs(110) Interface Formation Involving Cluster and Atom Deposition," *Phys. Rev. B* **40**, 2932-2939 (1989).
24. G.D. Waddill, C.M. Aldao, I.M. Vitomirov, S.G. Anderson, C. Capasso, and J.H. Weaver, "Metal Cluster Deposition on GaAs(110): Fermi Level Movement in the Absence of Metal-Induced Gap States and Defects," *J. Vac. Sci. Technol. A* **7**, 950-957 (1989).
25. S.G. Anderson, C.M. Aldao, G.D. Waddill, I.M. Vitomirov, C. Capasso, and J.H. Weaver, "Fermi Level Movement for Metal/n- and p-GaAs Interfaces: Effects of Temperature and Dopant Concentrations," *Appl. Phys. Lett.* **55**, 2547-2549 (1989).
26. I.M. Vitomirov, G.D. Waddill, C.M. Aldao, S.G. Anderson, C. Capasso, and J.H. Weaver, "Reversible Temperature-Dependent Fermi Level Movement for Metal-GaAs(110) Interfaces," *Phys. Rev. B - Rapid Commun.* **40**, 3483-3486 (1989).
27. S.G. Anderson, C.M. Aldao, G.D. Waddill, I.M. Vitomirov, S.J. Severtson, and J.H. Weaver, "Al/GaAs(110) Temperature Dependent Interface Formation and Overlayer Energy References," *Phys. Rev. B* **40**, 8305-8312 (1989).
28. C.M. Aldao, I.M. Vitomirov, G.D. Waddill, S.G. Anderson, and J.H. Weaver, "Dynamic Coupling Model: Temperature-, Dopant-Concentration, and Coverage-Dependent Schottky Barrier Formation," *Phys. Rev. B* **41**, 2800-2812 (1990).

29. C.M. Aldao, G.D. Waddill, P.J. Benning, C. Capasso, and J.H. Weaver, "Photovoltaic Effects in Temperature-Dependent Fermi Level Movement for GaAs(110)," *Phys. Rev. B Rapid Commun.* **41**, 6092-6095 (1990).
30. I.M. Vitomirov, C.M. Aldao, G.D. Waddill, C. Capasso, and J.H. Weaver, "Metal-InP(110) Schottky Barriers: Temperature-, Dopant-Concentration-, and Cluster Dependencies," *Phys. Rev. B* **41**, 8465-8476 (1990).
31. G.D. Waddill, C.M. Aldao, C. Capasso, P.J. Benning, Yongjun Hu, T.J. Wagener, M.B. Jost, and J.H. Weaver, "Thermally-Reversible Band Bending for Bi/GaAs(110): Photoemission and Inverse Photoemission Investigations," *Phys. Rev. B* **41**, 5960-5968 (1990).
32. G.D. Waddill, I.M. Vitomirov, C.M. Aldao, S.G. Anderson, C. Capasso, J.H. Weaver, and Z. Liliental-Weber, "Abrupt Interfaces with Novel Structural and Electronic Properties: Metal Cluster Deposition and Metal-Semiconductor Junctions," *Phys. Rev. B* **41**, 5293-5305 (1990).
33. Z. Liliental-Weber, E.R. Weber, J. Washburn, and J.H. Weaver, "Schottky Barrier Contacts on Defect-Free GaAs(110)," *Appl. Phys. Lett.* **56**, 2507-2509 (1990).
34. J.H. Weaver, Zhangda Lin, and F. Xu, "Surface Segregation at Evolving Metal/Semiconductor Interfaces," Chapter 10 in *Surface Segregation and Related Phenomena*, edited by P.A. Dowben and A. Miller (CRC Press, Boca Raton, 1990).
35. J.H. Weaver and G.D. Waddill, "Cluster Assembly of Interfaces: Nanoscale Engineering," *Science* **251**, 1444-1451 (1991).
36. T.R. Ohno, Y.-N. Yang, G.H. Kroll, K. Krause, L.D. Schmidt, Y. Kimachi, Y. Hidaka, S.H. Pan, and A.L. de Lozanne, "Cluster-Assembled Overlayers on High Temperature Superconductors," *Phys. Rev. B* **43**, 7980-7990 (1991).
37. B.M. Trafas, D.M. Hill, P.J. Benning, G.D. Waddill, Y.-N. Yang, R.L. Siefert, and J.H. Weaver, "Clustering and Reaction for Cr/GaAs(110): Scanning Tunneling Microscopy and Photoemission," *Phys. Rev. B* **43**, 7174-7184 (1991).
38. T. Komeda, F. Stepniak, and J.H. Weaver, "Schottky-Limit Barrier Heights for CO-coated Metal Clusters on GaAs(110)," *Appl. Phys. Lett.* **58**, 2809-2811 (1991).
39. C.M. Aldao, I.M. Vitomirov, G.D. Waddill, and J.H. Weaver, "Effects of Growth Temperature on Atom Distributions, Fermi-Level Positions, and Valence-Band Offsets for Ge/n-type InP(110) Heterojunctions," *Phys. Rev. B* **43**, 13952-13956 (1991).
40. T. Komeda, S.G. Anderson, J.M. Seo, M.C. Schabel, and J.H. Weaver, "Sm/GaAs(110) Interface Formation: Surface Instabilities and Kinetic Constraints," *J. Vac. Sci. Technol. A* **9**, 1964-1971 (1991).
41. I.M. Vitomirov, C.M. Aldao, and J.H. Weaver, "Structure of and Barrier Height at the Ag/InP Interface," and C.M. Aldao, I.M. Vitomirov, and J.H. Weaver, "Structure of and Barrier Height at the Au/InP Interface," Chapters 14.3-14.6 in *Properties of Indium Phosphide*, INSPEC, EMIS Datareviews Series No. 6 (United Kingdom, 1991) pp. 304-314.
42. T.R. Ohno, J.C. Patrin, U.S. Ayyala, and J.H. Weaver, "Ag Deposition onto Xe: Clustering, Incorporation, and Surface Attraction," *Phys. Rev. B* **44**, 1891-1895 (1991).
43. Y.-N. Yang, B.M. Trafas, R.L. Siefert, and J.H. Weaver, "Effect of Non-Thermally-Activated Hopping on Overlayer Morphology: An STM Study of Ti/GaAs(110)," *Phys. Rev. B* **44**, 5720-5725 (1991).

44. Y.Z. Li, J.C. Patrin, M. Chander, and J.H. Weaver, "Rare Earth Growth Structures on GaAs(110): Ce, Sm, and Yb," Phys. Rev. B **44**, 12903-12907 (1991).
45. J.M. Seo, Y. Chen, and J.H. Weaver, "Oxide Films Grown on GaAs(110) at 20 K: Stability during Cr Overlayer Formation," J. Appl. Phys. **70**, 4336-4341 (1991).
46. J.C. Patrin, Y.-Z. Li, and J.H. Weaver, "Cluster Growth of Al on Stepped and Unstepped GaAs(110) at 300 K: A Scanning Tunneling Microscopy Examination," Phys. Rev. B **45**, 1756-1761 (1992).
47. Y.-N. Yang, Y.S. Luo, and J.H. Weaver, "Ag Crystallite Formation and Coalescence on Hydrogen-terminated GaAs(110)," Phys. Rev. B **45**, 3606-3611 (1992).
48. Y.-N. Yang, Y.S. Luo, and J.H. Weaver, "Anisotropic Kinetics in Overlayer Growth: An STM Study of Ge/GaAs(110)," Phys. Rev. B Rapid Commun. **45**, 13803-13806 (1992).

**c. Books (and sections thereof) Submitted for Publication**

1. C.M. Aldao and J.H. Weaver "Atomic-Scale Chemistry of Metal-Semiconductor Interfaces," Chapter xx in *Contacts to Semiconductor Surfaces*, edited by L.J. Brillson (Noyes Publication, New Jersey, 1992).
2. J.H. Weaver, G.D. Waddill, I.M. Vitomirov, and C.M. Aldao, "Cluster-Assembled Interfaces," Chapter xx in *On Clusters and Clustering: From Atoms to Fractals*, edited by Peter J. Reynolds (North Holland, 1992).

**d. Books (and sections thereof) Published**

1. J.H. Weaver, "The Formation and Properties of Metal-Semiconductor Interfaces," Chapter 8 in *Electronic Materials: A New Era of Materials Science*, edited by J.R. Chelikowsky and A. Franciosi (Springer-Verlag, 1991) pp. 135-214.

**e. Technical Reports Published and Papers Published in Non-Refereed Journals**

1. J.H. Weaver, "Clusters, Their Growth, and Their Interaction with Surfaces," Naval Research Reviews, Office of Naval Research, Three / 1991, Vol. XLIII, pp 16-27.

**f. Patents Filed**

None

**g. Patents Granted**

None

#### **h. Invited Presentations at Topical or Scientific/Technical Society Conferences**

1. J.H. Weaver, "Reactions at Metal/Semiconductor Interfaces," Workshop on Synchrotron Radiation Research, The University of Western Ontario, London, Ontario, Canada, March 1987.
2. J.H. Weaver, "Metal/Semiconductor Interface Formation," Asia-Pacific Symposium on Surface Physics, Shanghai, China, April 1987.
3. J.H. Weaver, Invited lectures on metal/semiconductor interface formation and synchrotron radiation photoemission, Institutes for Physics, Semiconductor Physics, and High Energy Physics, Chinese Academy of Sciences, Beijing, April 1987.
4. J.H. Weaver, "Electronic Structures of Defects and Disordered Solids," US-Japan Seminar on Electronic Structure and Lattice Defects in Alloys, Honolulu, Hawaii, May 1987.
5. J.H. Weaver, "Growth and Characterization of Metal Overlayers on Compound Semiconductors," AIChE Conference on Emerging Technologies in Materials, Minneapolis, Minnesota, August 1987.
6. Zhangda Lin and J.H. Weaver, "Surface Segregation at Metal/III-V Semiconductor Interfaces," Solvay Conference on Surface Science, Austin, Texas, December 1987.
7. J.H. Weaver, "The Physics and Chemistry of Interfaces," Keynote lecture, "Advanced Materials: Science and Applications," The Royal Society of Canada, Windsor, Ontario, Canada, June 1988.
8. J.H. Weaver, "Metal-Semiconductor Interfaces," World Materials Congress: Interface Science and Engineering, Chicago, September 1988.
9. J.H. Weaver, "Surface and Interface Properties of Semiconductors and High  $T_c$  Superconductors," Argonne Colloquium on Frontiers of Surface Analysis, Argonne, September 1988.
10. J.H. Weaver, "Physics and Chemistry of Metal/Semiconductor Interfaces," Symposium on Chemistry and Defects in Semiconductor Heterostructures, Spring Meeting of the Materials Research Society, San Diego, April 1989.
11. J.H. Weaver, "Physics and Chemistry of Metal/Semiconductor Interfaces," American Vacuum Society, Albuquerque, May 1989.
12. J.H. Weaver, "Reactions at Semiconductor Interfaces," Special Seminar Series on Electronic Materials: A New Era of Materials Science, University of Minnesota, Minneapolis, May 1989.
13. J.H. Weaver, "Adatom Interactions on Semiconductor Surfaces," American Vacuum Society, College Station, September 1989.
14. J.H. Weaver, "Physics and Chemistry of Metal/Semiconductor Interfaces," International Conference on Semiconductor and Integrated Circuit Technology, Beijing, October 1989. [Conference cancelled]
15. J.H. Weaver, "Temperature-, Dopant-Concentration-, and Coverage-Dependent Schottky Barrier Formation," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
16. J.H. Weaver, NSF Workshop on "Interfaces and Atomic, Molecular, and Surface Physics," Perth, Australia, February 1990. [Unable to attend.]



17. J.H. Weaver, "Metal/Semiconductor Interfaces: Temperature-Dependent Atom and Cluster Deposition," Australian Physical Society, Perth, Australia, February 1990. [Unable to attend.]
18. J.H. Weaver, "Temperature-, Dopant-Concentration-, and Coverage-Dependent Schottky Barrier Formation," Seventeenth Annual Conference on Physics & Chemistry of Semiconductor Interfaces," Clearwater Beach, Florida, February 1990.
19. J.H. Weaver, "Temperature-, Dopant-Concentration-, and Coverage-Dependent Schottky Barrier Formation for III-V Semiconductors," Symposium on Metallization for Electronics Applications, Annual Meeting of The Minerals, Metals and Materials Society, Anaheim, February 1990.
20. J.H. Weaver, "Metal/Semiconductor Interfaces: Temperature-Dependent Atom and Cluster Deposition," Eighth International Conference on Thin Films (ICTF-8), San Diego, April 1990.
21. J.H. Weaver, "Clusters and Cluster-Assembled Interfaces," Materials Research Society, Boston, November 1990.
22. J.H. Weaver, Distinguished Lecturer, NSF Workshop on "Thin Film Science and Technology for the 21st Century," Evanston, Illinois, July/August 1991.
23. J.H. Weaver, "Clusters and Cluster-Assembled Interfaces," Gordon Conference, Brewster Academy, Wolfeboro, New Hampshire, August 1991.

*i. Contributed Presentations at Topical or Scientific/Technical Society Conferences*

1. F. Xu, Yoram Shapira, J.J. Joyce, F. Boscherini, D.M. Hill, S.A. Chambers, and J.H. Weaver, "Determining Concentration Profiles for Metal/III-V Interfaces: Au/GaAs(100), Au/InSb(110), Co/GaAs(100)," Fourteenth Annual Conference on Physics and Chemistry of Semiconductor Interfaces, Salt Lake City, January 1987.
2. M. del Giudice, J.J. Joyce, and J.H. Weaver, "Core Level Binding Energy Shifts, Thermodynamic Predictions, and Morphologies for Metal/Si and Metal/Ge Interfaces," American Physical Society Meeting, New York, March 1987.
3. M. del Giudice, R.A. Butera, J.J. Joyce, M.W. Ruckman, and J.H. Weaver, "Temperature Dependent Intermixing at the V/Ge(111) Interface," American Physical Society Meeting, New York, March 1987.
4. J.J. Joyce, M. Grioni, M. del Giudice, C. Aldao, and J.H. Weaver, "Interface Development of Rare-Earth/III-V Semiconductor Interfaces: Ce/GaAs(110) and Ce/InP(110)," American Physical Society Meeting, New York, March 1987.
5. F. Boscherini, Y. Shapira, C. Capasso, C. Aldao, M. del Giudice, and J.H. Weaver, "Exchange Reaction, Clustering, and Surface Segregation at the Al/InSb(110) Interface," American Physical Society Meeting, New York, March 1987.
6. S.A. Chambers, I.M. Vitomirov, S.B. Anderson, H.-W. Chen, T.J. Wagener, and J.H. Weaver, "High-Energy Auger and Medium-Energy Backscattered Electron Diffraction as a Probe of Ultra-Thin Epitaxial Overlayers, Sandwiches, and Superlattices," Third International Conference on Superlattices, Microstructures, and Microdevices, August 1987.

7. J.J. Joyce, C. Aldao, B.M. Trafas, and J.H. Weaver, "Island Formation and Metallic Screening at the In/Semiconductor Interface," 20th Annual Synchrotron Radiation Center Users Group Meeting, Stoughton, Wisconsin, October 1987.
8. C.M. Aldao, I.M. Vitomirov, F. Xu, and J.H. Weaver, "Photoemission Studies of a Nonabrupt Heterojunction: Ge/InP(110)," 20th Annual Synchrotron Radiation Center Users Group Meeting, Stoughton, Wisconsin, October 1987.
9. I.M. Vitomirov, F. Xu, C.M. Aldao, and J.H. Weaver, "Direct Evidence of the Onset of Indium Surface Segregation for Co/InP(110)," 34th National Symposium of the American Vacuum Society, Anaheim, November 1987.
10. C.M. Aldao, I.M. Vitomirov, and J.H. Weaver, "CoSi<sub>2</sub> Diffusion Barrier Modulation of the Au/Si(111) Interface Reaction," 34th National Symposium of the American Vacuum Society, Anaheim, November 1987.
11. D.M. Hill, F. Xu, Zhangda Lin, and J.H. Weaver, "XPS Measurement of Kinetic Parameters in the Ge/Si(111)-(7x7) Heterojunction at Elevated Temperatures," 34th National Symposium of the American Vacuum Society, Anaheim, November 1987.
12. S.A. Chambers, H.-W. Chen, T.J. Wagener, and J.H. Weaver, "Nucleation and Growth of Ultra-Thin Metallic Overlayers on Single-Crystal Transition Metal Surfaces," 34th National Symposium of the American Vacuum Society, Anaheim, November 1987.
13. M. Vos, F. Xu, J.H. Weaver, and H. Cheng, "Schottky Barrier Formation at Au/ZnSe(100) Interfaces," 35th National Symposium of the American Vacuum Society, Atlanta, October 1988.
14. Yongjun Hu, T.J. Wagener, Y. Gao, and J.H. Weaver, "Cluster Growth and the Evolution of Empty Electronic States," 35th National Symposium of the American Vacuum Society, Atlanta, October 1988.
15. G.D. Waddill, C.M. Aldao, I.M. Vitomirov, Y. Gao, and J.H. Weaver, "Influence of Temperature on Interface Reactions and Schottky Barrier Evolution for Au/InP(110)," 35th National Symposium of the American Vacuum Society, Atlanta, October 1988.
16. C.M. Aldao, I.M. Vitomirov, G.D. Waddill, and J.H. Weaver, "Morphology and Schottky Barrier Evolution for Au/InP(110): Deposition of Hot Atoms versus Cold Clusters," 35th National Symposium of the American Vacuum Society, Atlanta, October 1988.
17. I.M. Vitomirov, C.M. Aldao, and J.H. Weaver, "In Search of Symmetry: Evolution of the In/GaP(110) and Ga/InP(110) Interfaces," 35th National Symposium of the American Vacuum Society, Atlanta, October 1988.
18. G.D. Waddill, C.M. Aldao, I.M. Vitomirov, and J.H. Weaver, "Interface Formation by Atom and Cluster Deposition: Electronic and Structural Properties," 21st Annual Synchrotron Radiation Users Group Meeting, Stoughton, Wisconsin, October 1988.
19. C.M. Aldao, G.D. Waddill, S.G. Anderson, and J.H. Weaver, "Temperature Effects on Ti/GaAs(110) Interface Formation Involving Cluster and Atom Deposition," 16th Annual Conference on the Physics and Chemistry of Semiconductor Interfaces (PCSI-16), Bozeman, January 1989.
20. J.H. Weaver, C.M. Aldao, G.D. Waddill, and S.G. Anderson, "Temperature Effects for Ti/GaAs(110) Interface Formation Involving Cluster and Atom Deposition," Electronic Materials Conference, Boston, June 1989.

21. C.M. Aldao, M. Vos, and J.H. Weaver, "Interface Formation with Metal Ions and Neutrals: Influence on Interface Morphology and Schottky Barrier for Ag/InP(110)," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
22. G.D. Waddill, C.M. Aldao, and J.H. Weaver, "Symmetric Fermi Level Evolution at Metal-Semiconductor Interfaces: The Role of Substrate Dopant Concentration," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
23. S.G. Anderson, S.J. Severtson, and J.H. Weaver, "Temperature Dependent Al/GaAs(110) Interface Formation and Adatom Energy References," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
24. I.M. Vitomirov, G.D. Waddill, and J.H. Weaver, "Surface Interactions of Adatoms with GaAs(110): Reversible Temperature Dependent Charge Redistribution," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
25. B.M. Trafas, C.M. Aldao, R.L. Siefert, M. Vos, F. Xu, and J.H. Weaver, "CdTe(110) Interface Formation: Disruption, Cluster Formation, Segregation, and Metal-Anion Reaction Products with Adatoms of Ti, Pd, Ag, In, Au, Ce, and Al," 36th National Symposium of the American Vacuum Society, Boston, October 1989.
26. G.D. Waddill, T. Komeda, P.J. Benning, and J.H. Weaver, "Photoelectron Spectroscopy and Microscopy with Synchrotron Radiation," 37th National Symposium of the American Vacuum Society, Toronto, October 1990.
27. T. Komeda, B.M. Trafas, D.M. Hill, J.M. Seo, R.L. Siefert, M.C. Schabel, and J.H. Weaver, "Adsorption and Interaction of Sm on GaAs(110) Studied by Scanning Tunneling Microscopy and Temperature Dependent Photoemission," 37th National Symposium of the American Vacuum Society, Toronto, October 1990.
28. P.J. Benning, G.D. Waddill, T. Komeda, and J.H. Weaver, "Photoelectron Microscopy and Spectroscopy using Synchrotron Radiation," 23rd Annual Synchrotron Radiation Users Group Meeting, Stoughton, Wisconsin, November 1990.
29. G.D. Waddill, P.J. Benning, and J.H. Weaver, "Cluster Assembly of Interfaces," 23rd Annual Synchrotron Radiation Users Group Meeting, Stoughton, Wisconsin, November 1990.
30. B.M. Trafas, Y.-N. Yang, R.L. Siefert, and J.H. Weaver, "From Clusters to Crystallites: Scanning Tunneling Microscopy of Ag Growth on GaAs(110)," March Meeting of the American Physical Society, Cincinnati, Ohio, March 1991.
31. J.C. Patrin, Y.Z. Li, and J.H. Weaver, "Cluster Growth of Al on GaAs(110) Studied by Scanning Tunneling Microscopy," March Meeting of the American Physical Society, Cincinnati, Ohio, March 1991.
32. Y.Z. Li, J.C. Patrin, M. Chander, and J.H. Weaver, "Scanning Tunneling Microscopy of Ce, Sm, and Yb Structures on GaAs(110)," March Meeting of the American Physical Society, Cincinnati, Ohio, March 1991.
33. Y.-N. Yang, B.M. Trafas, R.L. Siefert, and J.H. Weaver, "GaAs(110) Terrace Width Distributions and Kink Formation," March Meeting of the American Physical Society, Cincinnati, Ohio, March 1991.
34. P.J. Benning, G.D. Waddill, T. Komeda, and J.H. Weaver, "Photoelectron Microscopy and Spectroscopy using Synchrotron Radiation," 13th Symposium on Applied Surface Science, Minneapolis, Minnesota, June 1991.

35. Y.Z. Li, J.C. Patrin, and J.H. Weaver, "Cluster Growth of Al on GaAs(110) Studied by Scanning Tunneling Microscopy," 13th Symposium on Applied Surface Science, Minneapolis, Minnesota, June 1991.
36. Y.N. Yang, Y.S. Luo, and J.H. Weaver, "The Impact of Anisotropic Kinetics on Epitaxial Growth: An STM Study of Ge/GaAs(110)," March Meeting of the American Physical Society, Indianapolis, Indiana, March 1992.
37. Y.S. Luo, Y.-N. Yang, J.H. Weaver, L.T. Florez, and C.J. Palmstrøm, "Effects of Annealing on the Surface Morphology of Decapped GaAs(001)," 39th National Symposium and Topical Conferences of the American Vacuum Society, Chicago, Illinois, November 1992..

**j. Honors/Awards/Prizes**

Physics News in 1990 (American Institute of Physics) for Cluster Assembly of Interfaces.

Naval Research Reviews for Studies of Clusters

Elected Fellow of the American Physical Society with a citation that reads "For studies of the fundamental parameters associated with overlayer growth on surfaces, with particular note of the development of cluster assembly as a means of creating novel interface structures."

**k. Number of Graduate Students Receiving Full or Partial Support on ONR Contract**

6

**l. Number of Postdoctoral Fellows Receiving Full or Partial Support on ONR Contract**

8

**Part II****a. Principal Investigator**

John H. Weaver  
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 421 Washington Ave. SE  
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**b. Cognizant ONR Scientific Officer**

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**d. Brief description of project**

This program focused on the growth of metallic overlayers on semiconductor surfaces. Its goal was to investigate interface chemistry for a wide variety of metal-semiconductor systems and determine the growth structures produced by varying the metal and the processes of deposition. It was hoped that defect-free interfaces could be created by controlling the chemistry or the growth process itself. Indeed, a novel process involving cluster deposition was developed and shown to give interfaces that were free of conventional semiconductor defects.

**e. Significant results of this project**

Throughout this program, we sought to use modern surface science techniques to investigate the chemical and physical properties of metal-semiconductor interfaces. Over a six year period, we were able to amass a large amount of information regarding semiconductor surface disruption induced by the growing metal overlayers, interface intermixing, and overlayer structures. This program produced approximately 48 refereed publications, 3 book chapters, and 23 invited papers. The cluster-assembly process received particular attention, being featured in Science, Naval Research Reviews, and a large number of speaking invitations.

Our studies pioneered the use of high resolution synchrotron radiation photoemission as a probe of the local environment produced on a surface as a result of adatom condensation, surface reaction, the formation of stable or metastable surface species, and the development of the metal overlayer. We showed that the evolution of the interface could be followed very precisely by analysis of core level binding energies and emission intensities, giving previously unavailable insight into surface/interface chemical configurations. Moreover, general patterns were discovered that reflected tendencies to react with either the anion or cation of the semiconductor and expell the other component from the (nanoscale) reacting zone. The expelled species was shown to play an important role in overall overlayer structures because, by segregating to the surface of the forming layer, they changed the surface free energy.

Our program pioneered investigations of interface properties for interfaces produced at low temperature. Those studies showed the effects of kinetics on interface reaction and segregation, demonstrating kinetic trapping that produced a nonequilibrium overlayer structure. Temperature- and dopant-concentration-dependent studies of growth on GaAs, InP and Si demonstrated the importance of the surface photovoltage in determining the position of the surface Fermi level and, hence, the apparent Schottky barrier for very thin layers. Such effects made it possible to determine the onset of metallic character and electrical transport at the surface.

Under this program we developed and explored processes associated with cluster deposition. The motivation was to produce an interface structure that was free of the disruption and chemical modification inherent with atom-by-atom deposition. Our work showed that defect-free interfaces could be formed by cluster deposition because the latter offered a unique thermodynamic pathway. In particular, we demonstrated that clusters could be formed at low temperature on a rare gas layer by exposing it to a flux of impinging metal atoms. If this buffer layer is formed on a clean semiconductor surface, then the clusters could be brought into contact with the semiconductor surface simply by warming the system to desorb the rare gas. Effectively, this process brought a cluster composed of hundreds or thousands of atoms (and therefore a parcel of matter having properties that were almost bulk-like) into contact with a solid under conditions of extreme cleanliness and minimal thermal energy. For GaAs(110) surfaces, we showed Fermi level positions in the bandgap that demonstrated the absence of conventional pinning sites in the semiconductor and the formation of ideal boundary layers.

*f. Graduate students and post-doctorals who worked on project*

M. del Giudice, postdoc (now U. Rome)  
 S.A. Chambers, postdoc (now Pacific Northwest Laboratory)  
 F. Xu, postdoc (now U. Calabria)  
 G.D. Waddill, postdoc (now Lawrence Livermore National Laboratory)  
 Peter (Y.-Z) Li, postdoc (now 3M)  
 Tim Ohno, postdoc (now Colorado School of Mines)  
 Neal (Y.-N.) Yang, postdoc (now U. Maryland)  
 Yu Chen, postdoc  
 C.M. Aldao, graduate student (now University Mar del Plata, Argentina)  
 I.M. Vitomirov, graduate student (now Xerox, Rochester)  
 D.M. Hill, graduate student (now Hewlett-Packard)  
 B.M. Trafas, graduate student (now Park Scientific)  
 Bill (Y.S.) Luo, graduate student  
 J.C. Patrin, graduate student